THE APPLICATION OF PSYCHOPHYSICAL DATA TO INDUSTRIAL EQUIPMENT DESIGN WITH SPECIAL CONSIDERATION TO SAFETY OF FEMALE OPERATORS

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A THESIS

Presented to

the Faculty of the Division of Graduate Studies

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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September 1951

Original Page Numbering Retained.

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Approved:

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Date Approved by Chairman September 17, 1951

ACKNOWLEDGEMENTS

I wish to express my appreciation to Professor W.N.Cox, Jr., who as chairman of the thesis reading committee contributed considerable time and effort throughout the development of this thesis. I thank Professor R.N.Trowbridge and Professor E.H.Loveland for their helpful suggestions as members of the thesis reading committee.

I am grateful to the persons and companies, far too numerous to mention who through their contribution of time and reference material have made this study possible.

Last but not least, I wish to express my gratitude to my wife, Dolores, whose patience and inspiration enabled me to complete this study.

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CHAPTER I

PURPOSE AND SCOPE

The purpose of research on the various biomechanical and psychological aspects of equipment design is to collect data on the capacities and limitations of individuals and to apply this data to engineering design problems to the end that the equipment which is finally produced will be better adapted to the requirements of the person who is to use it.

In the past engineering effort has largely been devoted to the improvement of equipment from the point of view of mechanical efficiency. Engineers have been aware of the desirability of designing equipment to meet the requirements of the operators. But in most cases they have lacked the scientific data necessary for the accomplishment of this aim.

Sufficient actual research has already been accomplished to show that improvements in operator efficiency which can be obtained from minor design changes frequently turn out to be much greater than improvements which can be obtained through months of intensive training or through careful screening of operators on the basis of aptitude.[1] In other words, variations in operator efficiency resulting from design changes in equipment sometimes are far more important than variations in efficiency which are due to the aptitude or training of operators. Almost all types of equipment, whether for civilian or military use, for business or pleasure, can be improved by adapting the equipment to the user, to a greater extent than has been prevalent up to the present time.

Many illustrations can be given of the way in which modern technology has produced machines without adequate concern for the capacities of the operators. For purposes of illustration an example showing how the defects in aircraft design have a direct bearing on the working efficiencies of air crews and on accidents is given.

On type of air transport had windshields with multiple curvatures which were faired to the curvature of the plane for aerodynamic efficiency and cleanliness. The distortion of pilot vision and high accident rate made it necessary to substitute flat panels and thereby make a change in the production line during World War II. The plane was reduced in speed by only 8 miles per hour, but the change in design cost millions of dollars in terms and time and money. A study of the human visual factors in a simple mock-up would have shown the error in such a design.

Research on equipment design is especially important as regards those items of equipment that are difficult or dangerous to use, that can be operated only by specially selected and trained operators, or that place a premium on the final degree of proficiency attained by the operator.

The major objective of this study is to show how industrial safety can be improved if mechanical design is more intimately related to the psychological and physiological characteristics of female operators. This implies that machines and working areas must be built around the operators rather than placing them in a setting without due regard for their individual requirements and capacities.[2] Unless this is done, it is hardly just to attribute so many accidents to human failure, as is usually the case. One of the first principles of accident prevention, therefore is to design equipment sufficiently adapted to the needs and characteristics of the operator. If this point of view is carried out in practice, fewer accidents should result, training costs should be reduced, and extensive redesigning of equipment after it is put to use will be minimized.

It is recognized that the scope of this subject is large. There are many related problems which should be thoroughly investigated before a completely comprehensive solution is possible. To exhaust all the possible related subjects is beyond the scope of this report. Among the most important factors seem to be display and control problems and their relationship to anthropometric characteristics of workers. These accordingly have been investigated and are included in this report. In many cases exhaustive search revealed that much additional experimentation and research is needed, particularly in the case of women operators.

CHAPTER II

DISPLAY PROBLEMS

The design of a display system involves the problem of presenting through instruments, necessary information that otherwise could not be readily perceived. For example, it would be difficult to know within precise limits what the pressure within a boiler was without the necessary instruments for conveying this information. Design of devices for providing this information is in many respects a psychological problem involving selection of the sense modality to be utilized, selection of the specific cues to be provided the operator, and choice of a method of indication.

All types of displays must of course, involve sensory discrimination in some form, but in most instances the stimuli to be differentiated greatly exceed the threshold requirements. Where difficulties exist, they are usually in the interpretation of the stimuli rather than their differentiation. Nevertheless, there are a considerable number of situations where sensory discrimination constitutes the basic problem.

VISION ASPECTS

The visual field of each eye subtends an angle of approximately 140 to 160 degrees in the horizontal and 130 to 145 degrees in the vertical meridian.[3] Small movements of the eyes will increase an operator's view of the surroundings, so that the "blind area" is reduced to approximately 40 degrees on either side of the midline of the back of the head.[4]

The widest limits of vision in all directions which eyes can fixate for distinct vision, is called the fixation field. It is found to be nearly circular with a diameter of about 100 degrees.[3] Vision downwards is somewhat over 50 degrees which is slightly greater than in the other directions.[6] While it would be undesirable for an operator to maintain a rigidly fixed position without eye, head or body movements, the layout of the working area should be such as to require a minimum of movement to view the whole operating area whether it is within or outside the working space. Equipment should be designed and working areas laid out so that only a minimum of movement is required, but in addition, they should be designed so as to allow free movement of the operator. For example, equipment involving a considerable number of display signals should be designed so that all the signals may be readily perceived with a minimum of head and body movements. On the other hand, the area should be constructed so that the operator may move head or body at his discretion.

VISUAL DISPLAYS

Whether we can see a tool, a piece of material or a control signal depends upon a number of considerations.

1. Size of Critical Detail

The absolute visual threshold of the normal eye is remarkably small. Under perfect conditions, the eye can detect a white spot on a black surface when it subtends an angle of only 10 to 12 seconds.[7]

Of course, no worker should be expected to manipulate objects which can barely be seen. Considerable discomfort and fatigue would result under such conditions. Therefore, a margin of safety should be allowed with regard to the size of objects which must be seen or discriminated by the eye. The design engineer must be aware that visual details must be made considerably larger than the size which can just be seen.

2. Contrast Between Object and Background

Studies of visual performance have shown that the discriminative capacities of the eye depend largely on contrast differences. These differences may be chromatic (e.g., a green object on a yellow background) or achromatic (a black object on a gray background). Studies have shown that achromatic contrast is a more effective factor than chromatic contrast in producing discriminable effects. In fact, the increased visibility that one obtains with the use of colors can often be attributed to the difference in brightness between colors rather than to the difference in hue. Thus for maximum visibility, black on white seems to the best arrangement.

3. Contrast Between Task Area and Surround

In many cases, the principles of contrast have been misapplied so that the working environment around the task area is much darker than the area itself. On first thought it may seem sensible to have the work area spot-lighted, but further consideration shows that greater eye comfort occurs when the working area is illuminated to the same degree as the background.[7] Visual tests have shown optimal performance when the background and surround area are equal. When the surround area is less, there is a slow falling off of visual performance. When the surround area illumination is greater than the background (as is the case with glare), visual efficiency falls off rapidly.[7]

4. Illumination of Work

Along with size, most people are aware of the importance of illumination as a determiner of visual comfort and efficiency.[10] Much has been written about this factor, and one can find numerous codes for lighting practice in schools, homes, offices and industrial situations.[11] There has been a tendency in recent years to set the illumination as high as possible, in the belief that the more light there is, the greater the ease of seeing. Vision experts believe this practice should be followed with caution, since the production of illumination above 50 foot candles is apt to produce glare points, high contrast and shadows, and other deleterious effects in the field of vision.[10] Because of the wide diversity of industrial tasks, it is impractical to list the recommended foot candle illumination levels for many of the possibilities. However, it may be well to note several representative illumination levels. (see table 1.)

Illumination of work and of the working area in relation to equipment design is important from the standpoint of both display and control. Controls must be illuminated in such a manner to reduce glare, diffusion and shadows to a minimum. The possibility of activating wrong controls is greatly increased when there is a shadowing effect or when glare is present. Further, poor illumination has a deleterious effect on our ability to attach the proper meaning to the visual display cues we may be required to receive.

5. Time of Exposure

The majority of industrial tasks are probably not affected by this variable, since the worker ordinarily controls the rate of his operations. Some jobs, however, such as high speed assembly work, require the operator to obtain visual information very quickly. In these cases it is important to recognize that the essential information may not be detectable or discriminable.[8] Fortunately, if you cut down on exposure time, you can get the desired results by increasing the illumination. Some of the other factors already described can be used in conjunction with illumination to overcome the loss of visual perception due to short exposure. Proper design, therefore, would call for an increase in the size of detail, an increase in the contrast, or a decrease in the glare when a fact operation depends on the eyes.

The fact that these various factors interact with one another is an important principle to understand in the design of visual displays.[8] When it is feasible and practical, one should attempt to

TABLE I[9]

RANGE FOR INDUSTRIAL ILLUMINATION

Tasks comparable to:	Recommended illumination (ft.-c)
Reading legible print	10 - 15
Sorting, rough inspection, bookkeeping, reading newsprint	15 - 20
Setting 6 point type, stitching, gross assembly work	30 - 40
Severe industrial tasks such as fine inspection, engraving, grading and sorting, proof reading	40 - 50

For workers who have some slight eye disabilities or those with corrections, the lower levels can be increased by 5 - 10 foot-candles.

use each variable to its maximum extent. When one or more of the factors are dictated by the operation itself, it is necessary to recognize that the other factors are available and can be utilized to create a more satisfactory visual display.

In the inspection of filled soft drink bottles, it is general procedure to pass light through the bottle in an attempt to detect any foreign material which may be present. In this instance constant factors are size of critical detail (at least this factor cannot be altered) and contrast. The factors that can be controlled are illumination and time of exposure. Both of these factors may be varied to give maximum detection ability.

AUDITORY ASPECTS

The primary physical characteristics of pure tones to which the human ear is responsible are frequency, intensity and duration of sound. Timbre is also of importance and should be considered. Frequency of sound is measured in the usual units of cycles per second. The range detectable by the normal ear is approximately 16 to 20,000 cps.[12] However, discrimination is poor at both extremes of this range. Therefore, in practice it is desirable to eliminate the extreme ranges for auditory signals.

Intensity is described in several different ways. Fundamentally, the intensity of sound may be measured by pressure (dynes per $cm.^2$), or by the rate of flow of sound energy (watts per cm.^{2}). A more convenient notation and one which is more in use is the decibel, which is expressed by:

$$N = 20 \log \frac{P_1}{P_2} = 10 \log \frac{E_1}{E_2}$$

where the E's are energies and the P's are pressures. N is the intensity of E in decibels (db.). The reference level P_2 is 2 x 10^{-4} dyne per cm.^{2}, which is approximately the pressure of a 1000 cycle tone at the hearing threshold for the average observer.[13] The upper intensity limit or tolerance is generally given as 120 db.[14]

Our ability to detect a change in frequency of a tone increases as the pitch increases from a very low value, and then becomes poor again for extremely high tones. The greatest pitch sensitivity is found for tones, the frequency of which is between 400 and 800 cycles per second.[15] This is the range we should work in if a pitch cue is to be utilized for giving us auditory information.

Intensity discrimination is also poor at low frequencies when the sounds are quite faint. Under these conditions our greatest sensitivity to a loudness change is at about 2000 cycles per second. For moderately loud tones (that is, above 40 db.) a normal ear is equally sensitive to loudness changes at all frequencies.

Timbre is the term applied to the characteristic overtone pattern of complex sounds which make it possible to identify a tone as being that of a violin, a piano, or a human voice. The timbre or quality of a sound depends on the number and type of harmonic frequencies present in a wave pattern, in addition to the fundamental frequency.

In order not to present a continous tone (which might become distracting or annoying), our auditory cues should be as brief as possible. This raises the question of how short they can be and still provide adequate pitch and loudness discrimination. The best evidence we have indicates that both of these types of discrimination approach values which are permissible if the tones were continous when the duration is approximately one twentieth of a second.[16] In other words we can get quite a bit of information into a fairly short burst of sound.

AUDITORY DISPLAYS

An auditory display is defined as a method of presenting information through instruments and the sense of hearing. Both speech and tone or noise signal devices are included in this definition. The importance of auditory displays lies in the speed with which information can be transmitted by them and in their value as a substitute for visual displays in cases where the visual sense is overloaded.

The most common type of auditory display uses speech as the signal. Physically, speech consists of vibrations that vary widely and rapidly in intensity and frequency. The range of useful frequencies is from about 125 to 5000 cycles per second. Most of the power in speech waves however, is carried by frequencies below 1000 cycles per second.[17] The normal range for speaking intensity is also small, being about 70 db., if speech is measured from a whisper to a shout.

Some speech sounds are more recognizable than others, particularly when listening is difficult, under conditions of noise and stress. Both physical and psychological factors share the responsibility for producing this difference in intelligibility. Intensity and frequency characteristics of speech sounds, duration, number of syllables, background noises, relation to other words in the language, and context are all determinants of word identification.

Auditory displays using a signal other than speech are sometimes used. The kinds of information which can be transmitted by the ability of the operator to differentiate the characteristics of the tones and then to attach the proper meaning to them.

The simplest type of signal is the yes-no type. If an event occurs, a signal is sounded and the operator acts accordingly. The successful transmission of the information is contingent upon the ability of the operator to hear.[18]

A more informative type of display is one which gives a variety of signals by changes in pitch, intensity, repetition rate and so on. For successful information transfer sensitivity to differences in sound signals is required by the operator.[18]

EFFECTS OF NOISE AND VIBRATION

From the standpoint of both safety and comfort of workers, the effects of noise and vibrations are important considerations in equipment design.

For vibrations in the audible range, the upper intensity limit or tolerance is generally given as 120 db. This is a safe working limit and ordinarily should not be exceeded. Davis[14] indicates the values:*

120 db.	threshold of discomfort
130 db.	threshold of tickle
140 db.	threshold of pain

An important question about man's reaction to sound is: Are there milder tolerances falling below 120 db? This question suggests problems of the distracting effect of industrial noise and the interference with conversation and communication.

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* These threshold values are for frequencies between 250 and 5000 cycles per second.

These tolerances are much more variable than those above; they vary both with the nature of the sound and with the conditions of the work and worker.

Distraction studies seem to point out three principles which are particularly important from the standpoint of safety. (a) Sudden loud sounds tend to speed a worker's movements. This speeding effect is observable when the sound is unrelated to the worker or his task, but it is even more marked when the sound is related to the immediate task. (b) Sudden loud sounds tend to disrupt the sequences of movements. Photographs of movement sequences often show irregularities for a few seconds after a fairly loud sound. (c) Increased sound levels or added noises may increase error rates at least temporarily; and, conversely decreased intensity levels or disapperance of sounds may reduce error rates.

The effects of low frequency vibrations transmitted to the body through the floor or a seat have been receiving increasing attention within the last few years. The increased interest is due primarily to practical needs arising from situations in which men must be exposed to large vibrational forces.

Chapanis [19] reports the findings of one fairly extensive study on the effects of vibration. This study revealed that vibrations adversely affected visual acuity. It was found that vibrations of between 25 and 40 cycles per second, and between 60 and 90 cycles per second have the worst effect. Although several theories have been offered, it is not known exactly why these vibrations have the worst effect upon visual acuity.

Another interesting finding of this study was that during vibration certain reflex actions were diminished, and for some amplitudes and frequencies reflex actions were completely surpressed.

The evidence here seems to indicate that equipment design engineers should be aware of the effects of noise and vibration. Although evidence is not conclusive, noise around the working area should be kept as low as possible. Further, vibrations should be damped completely, or if this not practical, kept out of the most dangerous areas.

Davis[14] points out it may be expected that when the intensity level reaches 120 db. the sound will be uncomfortably loud to persons with normal hearing. The discomfort will progressively increase as the level is raised above 120 db. At about 130 db. discomfort is supplemented by a tickle in the ear. This new experience increases progressively as the intensity level is further raised. Thus when one is exposed to an intensity of some 135 db. he will observe a very uncomfortable, unpleasant tickle in his ear, in addition to a loud sound. At 140 the uncomfortable tickle is further complicated by the inclusion of sharp pains in the ear. At intensities a few decibles above 140 the pain becomes too intense to be accepted voluntarily. Severe injuries may result from exposure to these intensities. Consequently, when working in intensities above 120 db., operators should wear special protectors or ear plugs to avoid aural damage.

CHAPTER III

CONTROL PROBLEMS

When an individual is required to perform repetitive work, to work at high rates of speed, occasionally to reach for, grasp and operate controls without the aid of vision, it is important that equipment be designed so that the operator can consistently operate it accurately, rapidly and safely. When accidents can be traced to inaccurate operation of equipment, or apparent employee carelessness in operating the equipment, it occasionally is found that the design of the equipment itself contributed to the accident. Had the visual displays and controls been designed and placed so that rapid and more accurate operator judgements and movements could have occurred, many of the accidents could have been prevented.

This requires that design and production engineers consider the tasks which the operator is to perform and the operator's limitations and abilities in performing these tasks.

In the design and use of controls, consideration should be given to location of controls, accuracy and ease of reaching and accuracy of operation. Further, consideration should be given to shape and color coding of knobs and direction of control movements.

LOCATION OF CONTROLS

In the placement of controls in the operator's workplace, the frequency with which each control is to be used, the manner in which it is to be operated, (type of movement, forces involved, speed and accuracy required), the sequence in which it is to be used with respect to other controls, and the conditions under which it is to be used all must be taken into consideration. Anthropologists have measured and charted the areas which are within the reach of the arms and legs. Likewise motion study engineers have found certain areas within a tabletop workplace where both one and two hands can operate satisfactorily. These areas as charted by anthropologists and motion study engineers provide basic areas for consideration when deciding where to place controls.

The forces which can be exerted in various hand, arm, foot and leg positions are also of prime importance in the location of controls. There have been only a surprisingly few studies made along these lines and much additional study and research is needed, particularly in the case of women operators.

ACCURACY of REACHING

Machine operators in certain instances must reach for controls without taking their attention from their work, and sometimes they reach for controls without looking for the controls even though visual ones could be used.

Studies have been conducted to investigate the accuracy and speed with which individuals can locate positions at approximately arm's length within the area easily reached by the extended arms independently when the subject was seated and not using visual cues.[20]

Results of this study were as follows: Accuracy was best for forward areas, and in the case of side areas, it was best for targets lower than the level of the soulders and for side targets near the front. Individuals tended to reach too low for the targets below shoulder level and too far to the rear for targets located on either side. Forward areas between the shoulder level and the waist line probably are ideal areas for the location of controls.

Further work indicates that the point of origin, reaching distance, and terminal point all influence the accuracy with which a free movement can be terminated with a minimum of error. The data in this study seem to indicate that controls which are located in forward areas should be located 6 to 8 inches apart if reasonable certainty is desired of grasping the correct or desired control when reaching blind.[21]

The data presented here point to the fact that the control area must be up so that unnecessary objects or controls, moving or dangerous parts, are not present. By eliminating unnecessary parts and by proper placement of controls, all evidence seems to point to a reduction in the inadvertent operation of controls, the erroneous operation of one control for another, and the accidnetal entanglement with a moving or dangerous part.

ACCURACY OF CONTROL OPERATION WITH ONE AND TWO HANDS

When considering where to place a control, the decision has to be made whether the control is to be operated by the left hand, the right hand, by either hand or by both hands together.

There is no important difference between the hands in reaction time. The preferred hand tends to be superior to the non-preferred hand in performing tasks where strength is the criterion.[22] The use of both hands to operate a continuous control task has been found superior to a one-hand control in most cases where accuracy was the criterion.[22]

NATURALNESS IN CONTROL MOVEMENTS

A recent study [23] indicates that when placing a control in a particular position, the relationships between the movement of the display desired (whether it be a pointer, a drill press head, or a crane boom) and the direction of the motion required by the control to produce the display movement should always be taken into account. This is particularly true when sudden and discreet movements of the control are required. It is important that a particular control handle should move so that the resultant display movement is in the "expected" direction in order to minimize the possibility of the control being moved accidentally in the wrong direction.

Fewer errors are made when an upward movement of the control produces an upward movement of the display, and a downward movement of the control produces a downward movement of the display.

Further, it was found that a forward movement of the control to move the display up and a backward movement to move the display down was the second best relationship.[24]

EMERGENCY CONTROLS

Although safety or emergency stops do not necessarily prevent accidents, they do assist in preventing errors or accidents from becoming more serious. An emergency control generally is to be operated by the individual making the error or having the accident, and obviously should be placed so that members of the body other than the one most likely to become caught or injured in the apparatus can be used for operating it.

The reaction time for the hands is less than for the feet. Therefore, other factors permitting, emergency controls should be placed so as to be activated by the hands. In addition, the control should be placed so that it could be reached by either hand with equal ease. The same applies to foot operated controls.

The control should be of such a nature that it does not have to be operated accurately. Further, it should only require a small amount of force to activate it.

Body operated controls may sometimes be used to advantage. Body operated controls are activated by pressure exerted on a bar or lever usually located on the table or machine edge. They should be of such a nature that they do not interfere with production of the operator, but located in a position that should the operator become caught, the control stop would be activated by only the slightest pressure or brush against it.

SHAPE AND COLOR CODING

When an operator reaches for and grasps a control handle which is placed in an area where other controls are located, and particularly where there is a possibility that the operator will occasionally reach for, grasp and operate the control without verifying visually which control has been grasped, wrong controls are sometimes manipulated which lead to serious accidents. Coding the control knobs with different shapes and colors has been found to reduce the time required for accurate operation of a series of controls.[25]

Tactual discrimination is very poor compared to the other capabilities of the eye. Yet it has been shown that equipment handles can be coded with respect to shape and/or size so as to virtually eliminate errors in control operation. Considerable knowledge now exists concerning the shapes which are maximally discriminable by the human being. We tend to divide our "touch world" into families of shapes. One family would be those shapes which are rounded, oval, curved or spherical. Another family is the square, angular and with many corners. Although we may confuse shapes within a family, we can distinguish between families fairly well.[25]

CHAPTER IV

HUMAN LIMITATIONS

In the design of many types of equipment the question of the limits of human ability in operation of the equipment is of special importance. Regardless of how well an item of equipment is designed in relation to the human requirements of the operator, there are always finite limits to the speed and accuracy with which the operator can use it. Such limitations must be studied and defined in order to predict whether it will be possible for individuals to use proposed new items of equipment.

The determination of human limitations is especially important in relation to the prevention of accidents. In order to be certain that equipment can be operated safely it is necessary to know not only the average performance of individuals who use it, but also what the range of human variability in its operation will be.

It should not be assured that all operators are perfect ones. In fact, they are often far below the ability as judged by the designer. If their duties are too complex, the cumulative burden is great, and the operators will exceed their limits of attention and ability. A wide margin of safety should be provided to eliminate any possibility of placing the operator near her maximum ability in regard to aptitude or effort, especially when adverse factors such as high speed, enter the picture.

TABLE II[26]

MEANS, MEDIAN AND STANDARD DEVIATIONS

OF MEASUREMENTS OF 10,042 WOMEN

MEASUREMENT*	MEAN	MEDIAN	STANDARD DEVIATION
Weight	133.48	128.72	25.98
Stature	63.16	63.19	2.48
Posterior arm length	23.00	23.00	1.17
Upper posterior arm length	13.28	13.27	.76
Anterior arm length	16.60	16.61	1.13
Sitting height	24.60	24.61	1.19
Span akimbo	34.30	34.42	1.47
Buttock - knee	22.60	22.68	1.20
Patella height	17.22	17.23	1.07
Bust height	45.05	45.09	2.30
Waist height	40.05	40.04	1.95
Crotch height	28.53	28.52	1.74
Bust girth	35.62	34.79	3.87
Waist girth	29.15	27.93	4.45
Hip girth	38.82	38.35	3.34
Upper arm girth	11.37	11.14	1.51
Elbow girth	10.35	10.25	.88
Wrist girth	6.01	6.00	.38
Forearm girth	9.75	9.65	.84
Maximum thigh girth	22.24	22.05	2.25
Ankle girth	9.31	9.25	.67

*All measurements are in inches except weight which is in pounds.

Table II is offered to show some of the measurements which have been collected by anthropometrists. Five of the terms may be unfamiliar to the engineer and hence warrant brief comment. Anterior arm length is measured with the arms held forward at shoulder height; span akimbo is the distance between the two elbows when the arms are held out to the sides at shoulder height, with the forearms flexed and the thumbs touched to the chest; buttock-knee is the seated length measured between the knee and the seat back, with the body in contact with the seat back; patella height is the distance from the sole of the foot to the top of the knee.

CONSIDERATIONS IN THE APPLICATION OF ANTHROPOMETRIC DATA TO DESIGN

Anthropometric data vs. Normal Operating Positions of the Body

A limitation in the use of a large proportion of the currently available body measurements is that the measurements were made in the classical body positions established as standards in physical anthropology without consideration of the position that the operator will assume in operating the machine.[27] For example, in the measurement of sitting height, the anthropologist will have the subject back of the table as far as possible until the backs of the knees hit the edge of the table. The trunk is erect as possible and the head is in the eye-ear horizontal. A comparative study of sitting height based upon measurements taken in this position and then in what is the normal sitting position showed differences of $2\frac{1}{4}$ inches, the 'natural' posture being the smaller value.[28] This then seems to indicate that if anthropometric measurements are to be used in the design of equipment, adequate allowances should be made to compensate for these discrepancies.

The Average Value Fallacy

The biologist, or the biologist in collaboration with a statistician, should advise on the adequacy of any selected measurements in providing for the future population, who will be required to operate the equipment or utilize the working space. Average values when given should be adequately described in terms of individual and group variations.

In problems of engineering design the average value cannot be employed directly, since by definition, arrangements based on an average would be unsuitable for 50 percent of the operators in a normally distributed group.[27] Provision for 90 or 95 percent of the potential operators will require identifying the correct cutoff point. Where for example, arm reach for the operation of manual controls is under consideration, the cutoff point should be well below the average reach; where strength of structure supporting one operator, or where body clearance is concerned, due consideration must be given to the half of the operators whose dimensions exceed the average values. These points loom as important safety considerations in view of present outlooks of manpower shortages.

In addition to identifying the correct cutoff point, design engineers should work in collaboration with a statistician in order to insure that provisions be made for the inclusion of adequate percentages of worker population to be included in the design of the equipment.

Stable Posture

Good design practice will permit machine operators to maintain an upright posture. Bending the body uses additional energy and reduces efficiency. In addition, it is generally accepted that there is a close correlation between accidents and fatigue, thereby increasing operator susceptability to accident. Further, it almost inevitably alters the visual field so that the view of the operating area may be modified or reduced. The maximum boundaries of the working area for the operation of manual controls, without displacement of the trunk must be considered in relating the operator and the machine. Several adequate and complete studies have been made for male operators. However, to the author's knowledge no studies have been made on the maximum reach measurements of female operators. Work of this nature is needed to establish safe and comfortable working areas for women operators.

Some situations will require or will result in more or less extensive body movements. It is fortunate that human beings have advantages which give them far more chance of maintaining an upright posture than inanimate objects with the same height of center and the same diameter of base support. By movement of the trunk the center of gravity can be adjusted to the position of the base. Further the base can be extended in any desired position by shifting the position of the foot. It is necessary, therefore, that a sufficient and satisfactory area be provided for the operator to carry out the compensatory shift of his foot or trunk.

Unobstructed Vision

An unobstructed field of vision is essential to avoid striking or colliding with objects and to maintain surveillance of controls, instruments and moving parts or materials in the immediate areas of operation. A survey of the limitations and capabilities of the visual field have been discussed in a previous section of this report. However, to gain additional emphasis it is suggested the visual field be unobstructed during all phases of the operation. Design equipment so that all moving objects and all controls are easily within the visual field during the entire operation.

Accessibility of Controls

The maximum dimensions of the working area for the operation of manual controls are determined by arm reach. The human body is so constructed that the boundaries of reach may be represented by a segment of an ellipse. The maximum dimension of the periphery is found at approximately 105 degrees to the right or left; dimensions diminish as the arm is brought to the zero position and as the arm is raised or lowered.

Placement of Controls for Operation at a Biomechanical Advantage

A large number of factors must be considered in locating controls within the area for manual or foot operation, even after the dimensions of the work space have been determined. These include such mechanical or operational factors as: the type and mechanism of the control, the importance of the control in emergencies, the speed of operation, the precision of operation and the forces required.

The major problem is to relate these factors to the operators capabilities. Knowledge in this area is very limited and in only a few cases have orderly studies been attempted. For the most part attention has been directed toward study of a specific device, rather than toward more generally applicable descriptions of biomechanics and human abilities. This is not difficult to understand, since the human body is so adaptable that a great number of descriptions would be required in order to provide information for the solution of a significant percentage of industrial situations.

CHAPTER V

APPLICATION OF THE DATA

Cases

Three cases have been selected for the purpose of showing how the foregoing information may be applied. The cases have been selected to give the widest range of coverage within the practical limitations of this study.

CASE NUMBER 1

FORK TRUCK

1. DESCRIPTION OF THE EQUIPMENT

Rating - light (2000 pounds at 24 inches)

Type - electrically powered

Travel speed - light - 4.75 mph

loaded - 4.25 mph

Elevating speed - light - 14.0 fpm

loaded - 12.0 fpm

Lowering speed - 40.0 fpm

Steering - steering gear is a commercial ball bearing worm gear requiring minimum effort to operate the trail wheel. Automotive type steering is used; that is, truck will turn in the same direction as steering wheel is turned.

Weight - 3700 pounds (light)

Brakes - Mechanical contracting brakes controlled by foot pedal located at conventional location at right of steering post. Brakes are automatically applied when driver leaves the seat. Brakes are equalized to insure equal braking on each wheel.

Lift and tilt controls - hydraulically operated lift and tilt mechanism, controlled by separate round knobbed control levers spaced $3\frac{1}{2}$ inches apart. The controls are located $28\frac{1}{2}$ inches from the seat reference point and 10 inches above it. (see fig.1)

Horn - the horn button is located 12 inches below the seat reference point on the left side of the truck.

Vision - vision on this model, as is true on most conventional type trucks, is through or around the load when traveling loaded; through or around the hoisting mechanism when traveling light.

IMPORTANT FACTORS IN DESIGN

Steering - the steering mechanism on this model seems appropriate for male operators. However, it was observed that female operators have some slight difficulty, exerting enough force to turn a loaded truck in a small radius. Two practical solutions are possible: the first is to increase the radius of the steering wheel. Due to the limitations of space of a compact industrial unit, an alternative method of increasing the velocity ratio * of the gear train seems to be the more appropriate.

Brakes:

The braking capacity of the truck appeared to be entirely sufficient. Brakes are used very frequently and should be inspected at frequent intervals and maintained properly. The mechanical advantage of the gear train was such that only a portion of the available leg force of the female operators need be used to adequately apply the brakes.

Controls:

Both the controls for lift and for tilt seem to be located in positions that require movement of the operator's body in order to activate them. In a normal seated position the average operator must move approximately 4 inches to reach the controls and an additional 2 inches if the control is to be activated in a direction away from the body. Moving the location of the controls from directly in front of the operator to a position approximately 45 degrees to the right seems to be all that would be necessary to bring them within range of the average operator without requiring extensive body movements. The controls are identical in color, size, and shape. Research evidence seems to indicate that better control would be brought about with the institution of different knobs, incorporating variations in shape and/or color.

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* V.R - $\frac{\text{Vel.Driver}}{\text{Vel.Driven}}$

Furthermore, the controls at present are located too close together to enable any degree of accuracy in "blind" reaching. It is suggested that the controls be located at least 6 to 8 inches apart to gain more accuracy in "blind" reaching. With the close tolerances and cramped space that frequently accompanies fork truck operation, blind reaching looms as an important consideration. Often the operator cannot afford to divert attention away from the surrounding area and must, therefore, reach for, grasp and activate the control without visually verifying what control has been grasped. (see fig.1.-A)

Horn

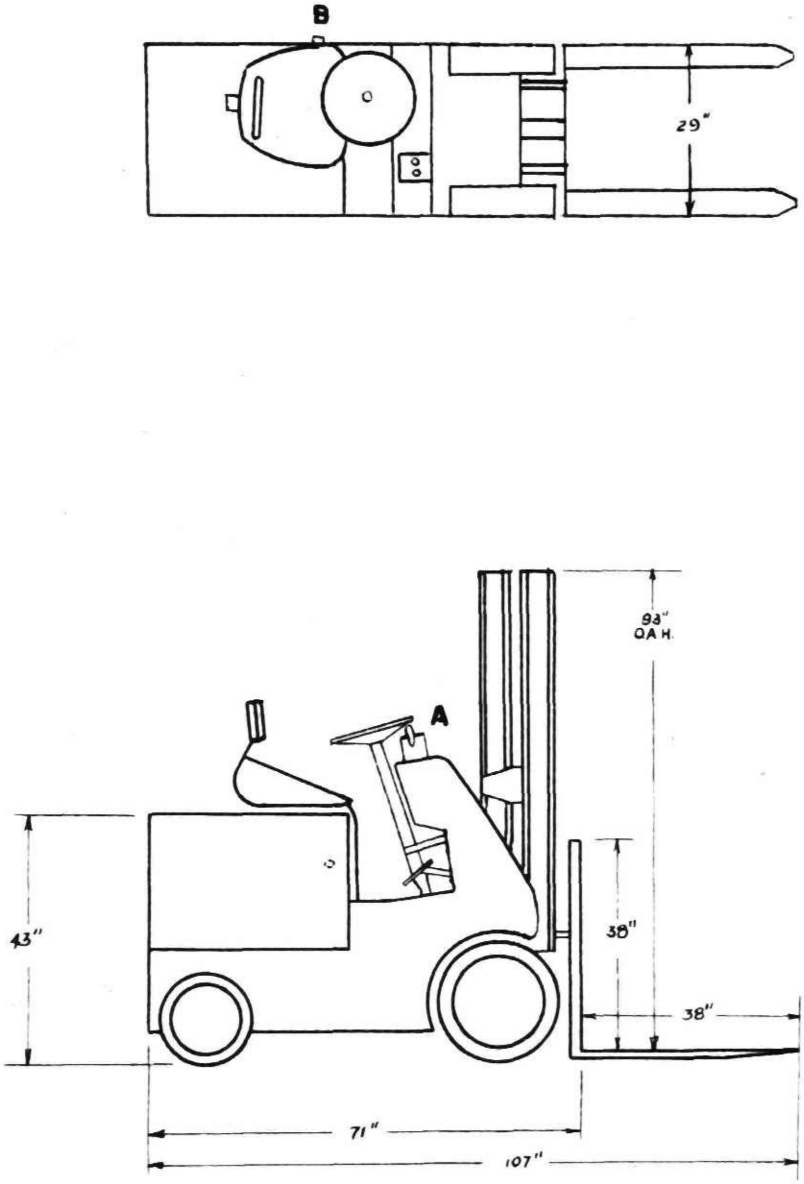
At present the operator is required to lean and reach down to the side of the truck to sound the horn.

If there is occasion to use the horn at all, the reason must be due to some oncoming or passing obstacle. In such a time of danger it seems impractical to require the operator to divert his attention from the potential danger to reach over the side to sound the horn. It is suggested the horn button be placed in the center of the steering wheel where it will be readily accessible. (see fig.1.-B)

Vision

Vision on fork trucks is characteristically poor. Conditions, such as limitations of space, many times cannot be altered so that the now popular design of fork trucks is the most practical. However, where space is not a limiting factor, side loading trucks

FIGURE NO. 1



seem the best answer to the vision problem.

CASE NUMBER 2

VERTICAL DRILL PRESS

1. Description of the equipment

Horsepower of motor ----$\frac{1}{2}$ h. p.

Drilling capacity -----$\frac{1}{2}$" dia.

Spindle speeds -----120 - 360 rpm.

Lead screw travel -----2"

Vertical adjustment of knee table
-----18"

Minimum distance spindle to center of column
-----12"

Maximum distance spindle to center of column
-----42"

Working surface of knee table
-----22" x 26"

Safe load limit on knee table
-----2000 lbs.

Minimum distance spindle nose to table
-----8"

Maximum distance spindle nose to table
-----30"

Maximum distance spindle nose to top of base
-----47$\frac{1}{2}$"

Maximum distance spindle nose to floor
-----53"

Overall height of machine
-----84"

Net weight of machine
-----3500 bls.

CONTROLS

Stop - start button located on back part of radial arm. completely out of reach to any one operating the machine. The same is true of the variable speed control.

The control for vertical adjustment of the drill is a set of three control levers emanating from a common center. The controls activate the drill downward when pulled forward, through an enclosed gear system.

The three controls are located on the right side of the radial arm. The knobs are equally spaced 120 degrees apart, and form a circle of approximately 18 in. diameter. All knobs are round.

The position of the normally operated control is approximately 71 in. above the floor.

The crank handle for raising and lowering the working table is located on the working table panel and directly in front of the normal operating position.

IMPORTANT FACTORS IN DESIGN

Both the stop - start buttons and the variable speed control dial seem to be located in a poor position. At present the operator is required to leave the operating position in front of the machine and walk around to the back to either stop, start or vary the speed. From the standpoint of both safety and efficiency, it is suggested these controls be placed within normal reach of the operator preferably on the side of the working table. This would prevent the operator from having to leave the drill running during the operation of stopping or changing the speed on the drill (see fig.2.-A)

The vertical adjustment control is located on the right side of the radial arm. For the convenience and comfort of left handed operators, it would seem justifiable from the cost standpoint to add a like set of controls to the left side of the radial arm.

In this floor model, as is true with all conventional vertical drill presses, considerable reach is required of the operators, particularly the short operators, to grasp and activate the control mechanism.

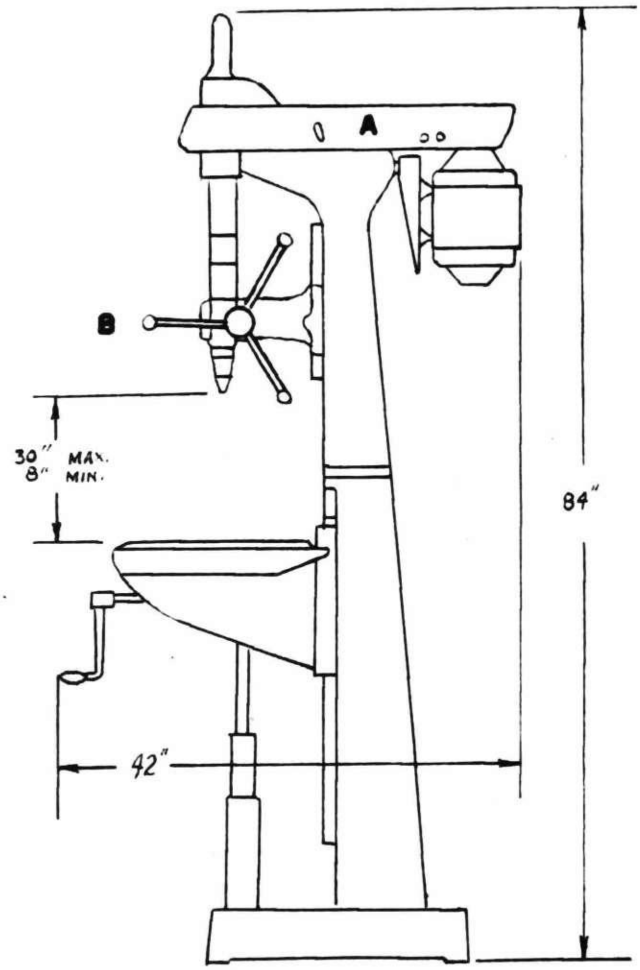
It would seem in most cases, with the exception of fine adjustments, control activation would be much less fatiguing, more comfortable and in many respects better if foot operated controls were used. There are many possibilities as to the actual mechanical details of such an arrangement, but it would appear a hydraulically operated system would be very suitable. (see fig. 2.)

The vertical adjustment control knobs were all the same shape. However, since all of the control levers carry on the same job it is permissible, in fact preferable to have the knobs the same shape. It is only in cases where controls perform different functions or activities that differentiation between knob shapes is desirable.

In this instance forward action of the control activates the drill downward. Studies as reported in an earlier section of this report show this is the expected movement and is therefore preferable.

Individually these machines are not particularly noisy nor do they set up much vibration. However it might reasonably be expected that many such machines will be found in the same building or work area. The combined effect of all the machines might result in a noise or vibration level deleterious to the safety and comfort of the operators. In the design and installation of the presses, these factors must be taken into consideration, and should it be necessary to do so, the machines must be modified in either design or installation.

FIGURE NO. 2



CASE NUMBER 3

ASSEMBLY OF WAFFLE IRON

Description of the operation

Operation

Assemble unit and cover to lower waffle iron grid casting

Equipment

One power nut driver

Conveyorized bench

Chair

Tote boxes and floor stands

Parts

Lower grid casting in box to operators left

Unit, porcelain ring and element subassemble, on conveyor belt in center of bench

Cover, in box on operator's right

Stud - 1 inch, in cardboard box on right

Nut, in cardboard box

Description of the Cycle

1. The operator reaches into the tote box on the left and selects one grid casting.
2. She lifts the casting, examining the edges, and face, and lays it on the bench, face down with the hinge lug toward her.
3. She reaches with left hand to a pile of units on the conveyor, picks up the top unit, and with both hands -
4. Places it on the grid casting with the wire leads above the hinge lug.

5. The right hand reached into the tote box on the right and obtains one cover plate which is placed over the leads onto the grid and unit.
6. The right hand then reaches into the box containing the studs, obtains one and inserts it through the cover into a tapped hole in the casting.
7. The right hand reaches into a second box, obtains a nut and starts it on the stud.
8. The right hand obtains the power driver, positions it and operates the driver.
9. The power driver is released and the completed assembly is placed on a stack of completed assemblies to the right of the work place.

IMPORTANT FACTORS IN DESIGN

Conveyorized bench - Moving so that the operator must work rapidly and accurately to complete the assembly before another unit is ready. The conveyor is a rubberized roller type with clearance of 5/8 inch between the belt and the conveyor frame. To eliminate the possibilities of both finger nips and loss of time through stud drops in this space, the conveyor belt should be increased in width so as to leave no gap between the belt and side frame. An alternative method and one which would be considerably less expensive would be moving the belt laterally. With properly placed guides all the clearance could be placed at the side furtherest away from the operator. Normally the entire assemble cycle is performed on only 3/4 of the belt width. Therefore the increased gap on the side furtherest from the operator would not in any way hamper the operation.

Chair - the chair in use now is the semi-stool type that is non-adjustable. It is suggested that an adjustable type be substituted to facilitate better operator comfort and efficiency, particularly the shorter operators. At present the shorter operators are at a considerable disadvantage due to their inability to reach all the parts without excessive reaching.

Power nut driver - at present the power driver is located to the left of the operator and above the conveyor belt. It is activated by a stop-start button which is located on the motor housing. One hand is required to position and hold the driver while the other hand is used to activate the stop-start button,

It is suggested that for better equipment design, one of two possible alternatives be considered. First, it would be advantageous to put the power activating switch on the end of the positioning lever. This would eliminate the use of two hands to operate the driver. The other alternative, which would accomplish the same end, would be to put the activating switch on the floor so that it could be activated by the foot.

At the present time there is no electrical ground lead on the driver. In the interest of operator safety in case of a short circuit, it is suggested a ground wire be installed.

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